

Low-Distortion Imaging Spectrometers

Distortion would be minimized by use of modified Offner optics.

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"Pushbroom" imaging spectrometers of a proposed type would exhibit little or no distortion in either the spectral or spatial direction. These spectrometers would feature modified Offner optics, which afford a desirable combination of compactness and a high degree of optical correction. Although Offner optics have been used in some spectrometer designs, their potential for eliminating distortion does not appear to have been exploited.

A pushbroom spectrometer includes a rectangular photodetector array with pixels arranged in rows (parallel to a spatial axis defined by a straight slit) and columns (parallel to the spectral axis). Light enters the spectrometer through the slit. Each point or pixel along the slit corresponds to a point or pixel along one spatial axis in the scene under observation. Thus, each column of pixels gives a readout of the spectrum for one point or pixel on a line that crosses the scene. The term "pushbroom" arises because in an action reminiscent of a pushbroom sweeping a floor, the field of view is swept through the scene, along a line perpendicular to the slit, to acquire spectral readouts from all pixels in the scene.

Accurate calibration is crucial for the extraction of detailed quantitative information from the readouts. The difficulty of calibration is reduced considerably if (1) the monochromatic image of the slit is straight and parallel to the rows of the photodetector array at any wavelength and (2) the spectrum of any point along the slit is straight and parallel to the columns of the array. When these conditions obtain, the length of a monochromatic slit image and the length of the spectrum remain constant across the array. Deviations from these conditions are denoted as spectral and spatial distortion, or "smile" and keystone error.

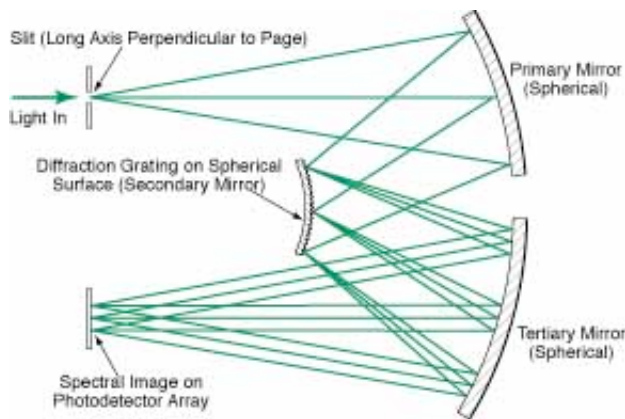
Although it may seem obvious that the above types of distortions should be minimized, values of as much as 1 or 2 pixels have been accepted in previous spectrometer designs. Recent studies have shown that to preserve the integrity of spectral image data, one must limit smile to no more than a hundredth of a pixel, while similar stringent requirements apply to the keystone error as well as the variation of the pixel spectral response function. These requirements push accuracy and optical-correction requirements into a hitherto unexplored range, where, it turns out, a modified Offner configuration offers design solutions.

In a spectrometer of the classical Offner configuration, there are two concentric mirrors: a concave mirror and a convex mirror with twice the curvature of the concave one. The concave mirror is used twice, as both the primary and the tertiary mirror. A diffraction grating is deposited on the convex mirror. This optical system has a nominal magnification of -1. The system can provide good correction at high f number (ratio of focal length to aperture diameter) and for low-dispersion gratings, while simultaneously limiting smile. But for lower f number and/or larger grating dispersion (which is often needed), it is normally found advantageous to have separate primary and tertiary mirrors (see figure), the curvatures and separations of which can be chosen independently in the design-optimization process.

The design-optimization process includes the use of a merit function based partly on spot size and partly on intersections of specific light rays with the image plane to characterize the centroids of ray distributions as

indicators of smile. With that merit function, it has been found possible to control smile and keystone error to essentially arbitrary accuracy at the design stage, over a wide range of designs. These designs all involve centered mirrors with purely spherical surfaces (no aspherical terms), and no tilts. Tolerance analysis has revealed that manufacturability and alignment are within reason.

In controlling distortion and spot size simultaneously, it is important to use the appropriate grating order of diffraction; in particular, the simplest designs are usually obtained by use of the +1 order, for which the angle of diffraction is less than that of the 0 order. Diffraction gratings that would satisfy stringent requirements for low distortion could be fabricated on the convex mirrors by electron-beam lithography. The detailed grating characteristics, including wavelength-dependent apodization and phase errors of multichannel gratings should be understood and controlled, for an actual spectrometer to approximate its design performance. Aberration correction by the grating could also be used to advantage in controlling the performance variation across the field.



Modified Offner Spectrometer Optics can be optimized to minimize both spot size as well as spectral and spatial distortions.

This work was done by Pantazis Mouroulis of Caltech for NASA's Jet Propulsion Laboratory. For further information, access

*the Technical Support Package (TSP) **free on-line at www.nasatech.com under the Physical Sciences category.***

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